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# Metabolic Profile of the Ironman World Championships: A Case Study

John S. Cuddy, Dustin R. Slivka, Walter S. Hailes,  
Charles L. Dumke, and Brent C. Ruby

**Purpose:** The purpose of this study was to determine the metabolic profile during the 2006 Ironman World Championship in Kailua-Kona, Hawaii. **Methods:** One recreational male triathlete completed the race in 10:40:16. Before the race, linear regression models were established from both laboratory and field measures to estimate energy expenditure and substrate utilization. The subject was provided with an oral dose of  $^2\text{H}_2^{18}\text{O}$  approximately 64 h before the race to calculate total energy expenditure (TEE) and water turnover with the doubly labeled water (DLW) technique. Body weight, blood sodium and hematocrit, and muscle glycogen (via muscle biopsy) were analyzed pre- and postrace. **Results:** The TEE from DLW and indirect calorimetry was similar: 37.3 MJ (8,926 kcal) and 37.8 MJ (9,029 kcal), respectively. Total body water turnover was 16.6 L, and body weight decreased 5.9 kg. Hematocrit increased from 46 to 51% PCV. Muscle glycogen decreased from 152 to 48 mmol/kg wet weight pre- to postrace. **Conclusion:** These data demonstrate the unique physiological demands of the Ironman World Championship and should be considered by athletes and coaches to prepare sufficient nutritional and hydration plans.

**Keywords:** doubly labeled water, water turnover, muscle glycogen, hydration, ultra-endurance

Recently, researchers have begun characterizing the physiological demands of Ironman triathlons. Researchers have described the metabolic demands of the race,<sup>1</sup> changes in blood sodium and plasma volume,<sup>2</sup> and provided nutritional recommendations.<sup>3</sup> Similarly, our laboratory has determined that a half Ironman triathlon utilizes a high rate of muscle glycogenolysis.<sup>4</sup>

The use of doubly labeled water (DLW) is considered the gold standard for determining total energy expenditure (TEE) and total body water turnover ( $\text{rH}_2\text{O}$ ) in free-living environments. The methodology can be used during shorter exercise duration ( $<24$  h) if  $\text{rH}_2\text{O}$  and TEE are high.<sup>5</sup> The purpose of this study was to determine the metabolic profile during the 2006 Ironman World Championship, in Kailua-Kona, Hawai'i.

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## Methods

### Experimental Procedures

Before testing, the participant provided written informed consent for participation in the study after the protocol was approved by the university institutional review board. A trained 39-year-old male participated in the 2006 Ironman World Championships in Kona, HI. Before the race, the subject completed a maximal cycle ergometer test (Velotron, RacerMate Inc., Seattle WA) using a graded protocol (initiated at 95 W and increased 35 W every 3 min) and a maximal treadmill test (5 min stages at 2.2, 2.7, and 3.1 m·s<sup>-1</sup> at 1% grade, followed by 1 min stages of 3.6, 4.0, 4.5, and 5.4 m·s<sup>-1</sup> until volitional exhaustion) on a motorized treadmill (Trackmaster, Full Vision, Inc., Newton KS). Expiratory gasses were analyzed using a calibrated Parvo Medics TrueOne 2400 metabolic cart (ParvoMedics, Sandy, UT). On a separate visit the subject completed steady state stages (4 min per stage) at 45, 55, 65, and 75% of maximal watts for the bike test. Steady state metabolic profile for running was determined from the maximal treadmill test. In addition to the laboratory testing, the subject completed steady state stages on site in Kailua-Kona several days before the race wearing race gear (bike, clothing, shoes, etc.) using a portable metabolic system (Cosmed K4b2 USA Inc., Chicago, IL) at the same laboratory intensities for the bike and 3.2, 3.6, and 4.1 m·s<sup>-1</sup> for the run. Watts were measured using a digital power meter (SRM Power Systems, Colorado Springs, CO) and run speed was measured with a wrist-worn GPS unit (Garmin Forerunner 301, Garmin International, Inc., Olathe, KS). These tests were done following 5 d of acclimatization to the race environment. Tests were completed during the same time of day the subject was expected to be biking and running.

### Energy Expenditure

**Doubly Labeled Water.** On the Wednesday night before the Saturday race (2200), approximately 64 h before the race, the subject consumed an oral dose of <sup>2</sup>H<sub>2</sub><sup>18</sup>O (100 g; 1.82 g of <sup>18</sup>O per kg of total body water, 0.13 g of <sup>2</sup>H<sub>2</sub> per kg of total body water.) The dosing procedures and analysis were similar to previous work completed by this laboratory.<sup>6-8</sup> Briefly, urine samples were collected at the following time points: immediately before ingesting the dose, AM second voids on Thursday, Friday, and Saturday (prerace sample), and PM voids on Thursday, Friday, and Saturday (postrace sample). Pre-race urine was collected as close to the beginning of the race as possible (36 min) and the post-race urine was the first void following the end of the race (1:12:44 postrace). On the first night, overnight and first void urine volumes were collected and measured. The isotopic enrichments of urines collected before and after the race were used to determine CO<sub>2</sub> production. Isotope enrichments were measured by isotope ratio mass spectrometry. To account for a shift in background enrichment, two non-dosed subjects from the same geographical location provided urine samples at the same time points as the research participant.

Because the measurement period of interest was short, it was not possible to recalculate TBW at the end of the race. Prerace TBW was estimated based on body weight changes relative to the initial time of isotopic dosing and the TBW/body

weight relationship established at that time. Postrace TBW was estimated from the prerace body weight and subtracting the estimated kilograms of endogenous fuel use as calculated from race TEE. For TEE, average TBW during race was used:  $(\text{prerace TBW} - \text{postrace TBW})/2$ . To account for endogenous use to determine TEE, the following equation was used:  $(\text{TEE} - \text{EI})/[(4 + 9.5)/2]/1000$  (EI: energy intake). This accounts for exogenous fuel use by subtracting it from TEE. Endogenous loss is assumed to be 50% fat and 50% CHO. Additional weight loss beyond this was assumed to come from water loss. These adjustments are similar to those used previously.<sup>9</sup>

**Linear Regression** Energy expenditure during the swim portion of the race was estimated using equations established by Kimber et al.<sup>1</sup> Using the combined steady state data from the laboratory and field tests, linear-regression equations were established for cycle watts and running speed for  $\text{VO}_2$  and  $\text{VCO}_2$ . The  $r^2$  values for  $\text{VO}_2$  were 0.90 and 0.96 for the bike and run, respectively. The  $r^2$  values for  $\text{VCO}_2$  were 0.98 and 0.97 for the bike and run, respectively. Energy expenditure was estimated from average hourly watts (SRM Power Systems, Colorado Springs, CO) during the ride segment. Similarly, energy expenditure was estimated during run segments based on pace from official race split times at miles 5.2, 17.6, and 26.2. Substrate oxidation was estimated using equations previously established by Peronnet and Massicotte:<sup>10</sup>

$$\text{CHO (g}\cdot\text{min}^{-1}\text{): } 4.585 \times \text{VCO}_2 - 3.226 \times \text{VO}_2$$

$$\text{Fat (g}\cdot\text{min}^{-1}\text{): } 1.695 \times \text{VO}_2 - 1.701 \times \text{VCO}_2$$

There was no accounting for alterations in substrate oxidation over time or relative to ingested macronutrients during the event. To coincide with the timing of the DLW energy expenditure estimate, resting values were used to determine energy expenditure and substrate utilization during the 36 min prerace and at 1:12:44 postrace.

## Muscle Glycogen

Muscle biopsies were obtained 2.5 h pre- and 0.5 h postrace from the right vastus lateralis using a Bergstrom percutaneous muscle biopsy needle with aid of suction.<sup>11</sup> Muscle glycogen was analyzed in triplicate using an enzymatic spectrophotometric method.<sup>12</sup>

## Blood and Body Weight

Blood was collected 0.5 h pre- and 0.5 h postrace from the antecubital vein and analyzed for hematocrit using an i-STAT blood analyzer (Abbott Laboratories, Abbott Park, IL). Body weight was measured pre- and postrace using a calibrated digital scale (Newline Model No. SBB0810, Mii Wintime International, Inc., Hicksville, NY).

## Exogenous Food Intake

Exogenous food intake was recorded postrace by participant interview. Supplemental CHO was consumed in the form of bars, gels, and liquids. Exogenous CHO utilization is not accounted for in the energy expenditure of CHO and fat. Premeasured amounts were used exclusively during the bike, but fluid intake on the run was approximated at 17 servings totaling an estimate of 1,981 mL. Since fluid was ingested via paper cups, it is possible that there is some error in this estimation; however, we think the error would only be in the range of  $\pm 296$  mL.

## Results

Descriptive data is shown in Table 1. Participant race finish time was 10:40:16. The fuel utilization profile, body weight, race splits, race speeds, transition times, and exogenous food intake are in Table 2. Total rH<sub>2</sub>O was 16.6 L per race. Blood hematocrit increased from 46 to 51% corpuscular volume (PCV), and muscle glycogen decreased from 152 to 48 mmol·kg<sup>-1</sup> wet wt. Race day ambient temperatures ranged from 28–31°C and relative humidity from 67–100%.

## Discussion

Accepting potential limitations of the employed methodologies in a field environment, this study extended the application of the DLW methodology and muscle biopsies to capture physiological data in a performance setting. The primary finding from this study at the Ironman World Championships was the DLW methodology can be used to assess TEE and water turnover during a short time period (<24 h) in a field situation. It is likely that determining TEE during short time frames is only possible during arduous exercise tasks, such as Ironman triathlon or ultra-running, since there must be high water turnover in a short time period to detect the necessary changes in isotopic elimination rates, that is, <sup>2</sup>H vs <sup>18</sup>O loss. The TEE from DLW was similar (0.45 MJ [103 kcal] difference) to the linear regression model estimation used to assess energy expenditure during the prerace, race, and postrace time periods. The estimated energy expenditure via indirect calorimetry during the race (excluding the pre- and postestimates of energy expenditure) was 36.1 MJ (8,617 kcal) and agrees with previous estimates<sup>1</sup> of energy expenditure during Ironman competitions.

**Table 1 Subject descriptive data**

Age	Height	Weight	Peak VO <sub>2</sub> , Bike	Peak VO <sub>2</sub> , Run
39 y	185.4 cm	76.0 kg	4.92 L·min <sup>-1</sup>	5.40 L·min <sup>-1</sup>
			64.7 mL·kg·min <sup>-1</sup>	71.1 mL·kg·min <sup>-1</sup>

**Table 2 Comparison in total energy expenditure (TEE) using mode-specific regression equations developed from indirect calorimetry and the doubly labeled water (DLW) method**

	Time	Speed (m·s <sup>-1</sup> )	TEE (Ind. Cal.), MJ (kcal)	TEE (DLW), MJ (kcal)	CHO (g)	Fat (g)	BW (kg)	CHO Intake (g)
Pre	36:00		0.5 (121)	Initial collection			78.6	
Swim	1:15:51	0.8	3.4 (805)	↓	141	27	↓	0
T1	4:29		0.2 (45)		8	2		
Cycle	5:19:40	9.4	21.4 (5,123)	↓	925	156	↓	404
T2	4:47		0.2 (48)		8	2		
Run	3:55:29	3.0	10.9 (2,596)	↓	288	161	↓	228
Post	1:12:44		1.2 (291)	Postcollection			72.7	
Total	12:29:00		37.8 (9,029)	37.3 (8,926)	1,370	348		632

*Note.* TEE (Ind. Cal.) = total energy expenditure calculated from mode-specific regression equations based on cycle power and running pace (The  $r^2$  values for  $\text{VO}_2$  were 0.90 and 0.96 for the bike and run, respectively. The  $r^2$  values for  $\text{VCO}_2$  were 0.98 and 0.97 for the bike and run, respectively); TEE (DLW method) = total energy expenditure calculated from doubly labeled water isotope elimination; Pre = prerace preparation from sample collection to race start; T1 = swim-to-bike transition; T2 = bike-to-run transition; Post = postrace period from race finish to sample collection; CHO and fat are estimated via indirect calorimetry using previously established equations;<sup>10</sup> BW = body weight.

During the Ironman, muscle glycogen decreased by 68%, considerably less than the half-Ironman event (–83%). Since this was the same participant in both studies, there are several possibilities for the difference in muscle glycogen utilization between races: the Ironman is completed at a lower intensity, the participant may have developed further adaptations for greater fat utilization, and prerace muscle glycogen was lower (152 vs 227 mmol·kg<sup>–1</sup> wet wt. for the full and half Ironman events, respectively). It is likely that the total CHO utilization estimates via indirect calorimetry underestimated CHO use due to the increased exogenous intake during the race (laboratory and field gas measurements were completed in a fasted state). However, using individualized equations and combining both laboratory and field tests provided the highest level of accuracy possible to determine substrate utilization for a field study short of having the participant wear a portable metabolic system during the race. Assuming 100% oxidation of exogenous intake, substrate utilization during the ride was 44% and 56% and during the run 79% and 21%, exogenous and endogenous oxidation, respectively. This emphasizes the massive dependency on the Ironman racer at maximizing exogenous intake and oxidation.

Body weight loss was substantial during the race (5.9 kg, or 8% of body weight) and hematocrit increased 5%, suggesting a decreased plasma volume. This response is atypical for Ironman and other ultra-endurance events, where plasma volume maintenance or increases of approx. 10% have been observed.<sup>2</sup> The participant demonstrated no symptoms that required medical care. The high body weight loss, increased hematocrit, the participant's intense thirst, and difficulty to urinate for several hours after the race suggest that he was dehydrated. It is possible that dehydration may have contributed to the slowed run pace for the final three-fourths of the marathon.

Total rH<sub>2</sub>O measures the input and output of fluids through the body over a given time period. The measure does not necessarily reflect the fluid demands to maintain euhydration during a specified task; rather, the measure is dictated by self-selected fluid intake habits of the individual and rate of loss based on environment and work effort. Total body water turnover during the race (including the pre- and posttime) was 16.6 L, or 1.33 L·h<sup>–1</sup>. In previous studies with wildland firefighters<sup>7</sup> and Air Force Special Operations Forces airmen,<sup>6</sup> water turnover rates were 0.37 and 0.28 L·h<sup>–1</sup>, respectively. These are strenuous occupations that demand work over extended periods of time. In the current study, water turnover was approximately 4 to 5 times these rates. Thus, completing an Ironman triathlon, especially in Kailua-Kona, incurs a high rate of total body water turnover and a unique hydration challenge for unacclimatized race participants. Total body water turnover during an Ironman can range from 15 to 20 L per race, providing indications of fluid ingestion for participants. Further research should be completed to help minimize the potential for heat-related illnesses specific to Hawaii Ironman.

## Practical Applications and Conclusions

These data demonstrate the challenging metabolic demands of the Ironman World Championships. Athletes and coaches should be aware of the unique stresses involved by participating in Ironman World Championships in order to prepare an adequate nutritional and hydration plan.

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